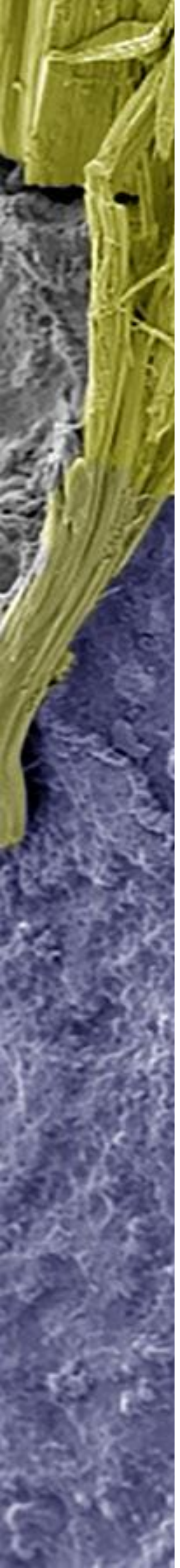

Ultra-Lightweight Thermoplastic Polymer/Polymer Fiber Composites for Vehicles (Inter-Lab Project)

Project ID: mat199

June 22, 2021

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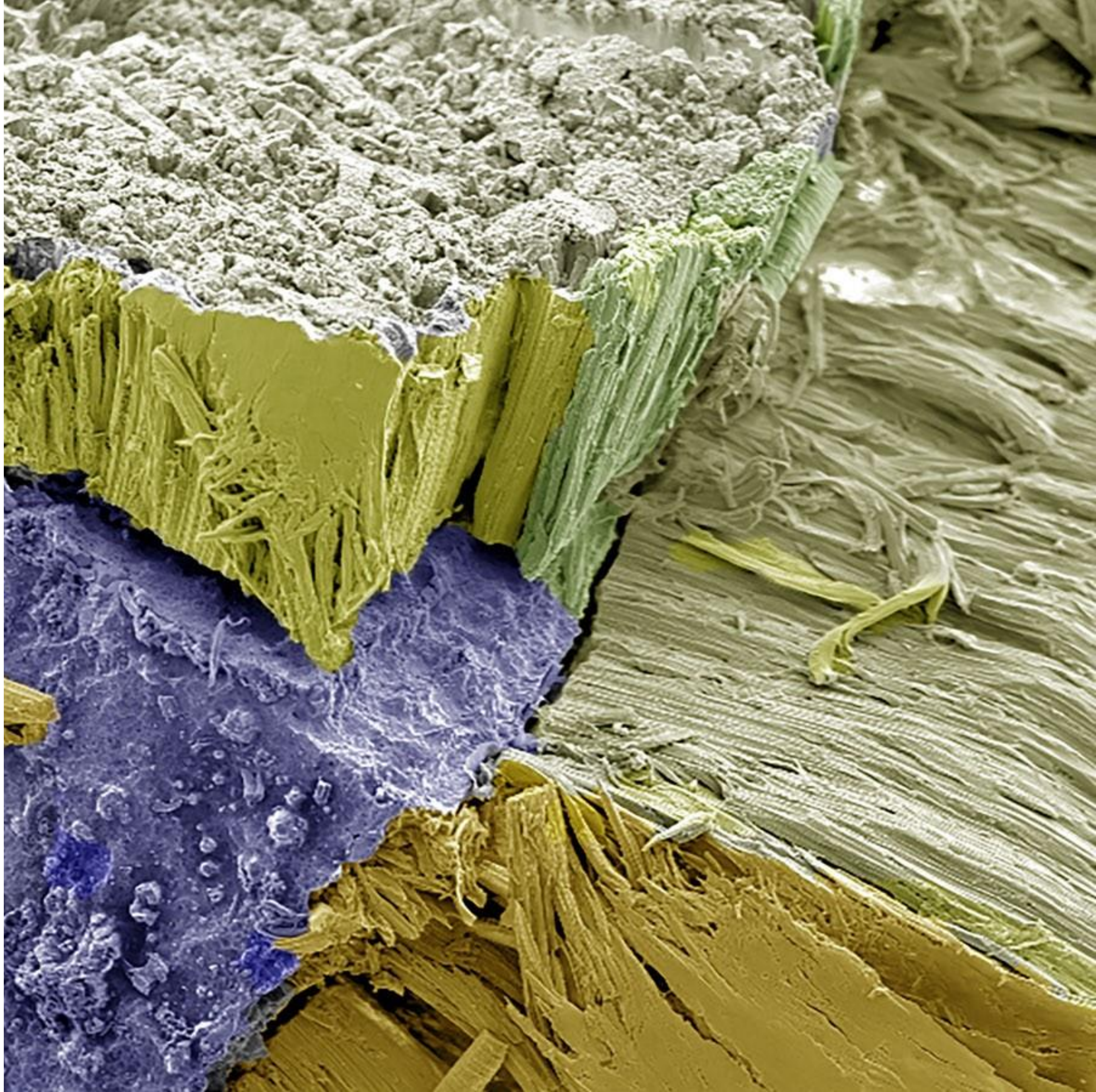


Overview

Timeline

Start date: September 2020

End date: September 2023

20% Complete

Budget

Total project funding: $960,000

Fiscal Year 2021: $320,000

Barriers

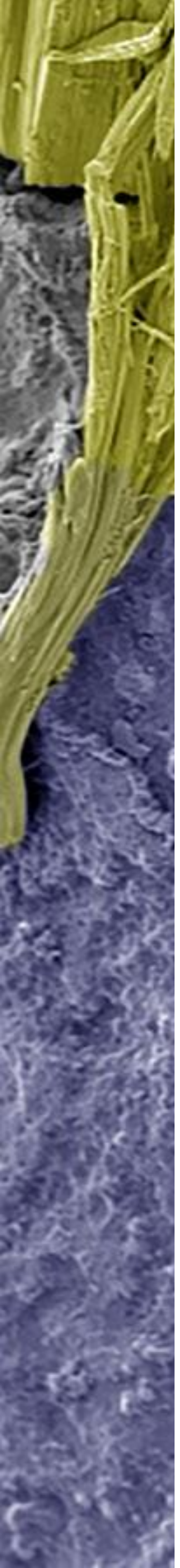
Lack of infrastructure for producing lightweight, high strength materials such as carbon fiber composites

- ❑ Low-cost, high volume manufacturing
- ❑ Low-cost carbon fibers
- ❑ Recyclability

Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials Workshop Report, February 2013

Partners

Oak Ridge National Laboratory (ORNL)



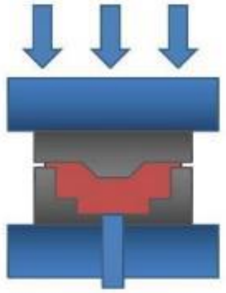
Relevance

300 kg steel = 100 kg plastic

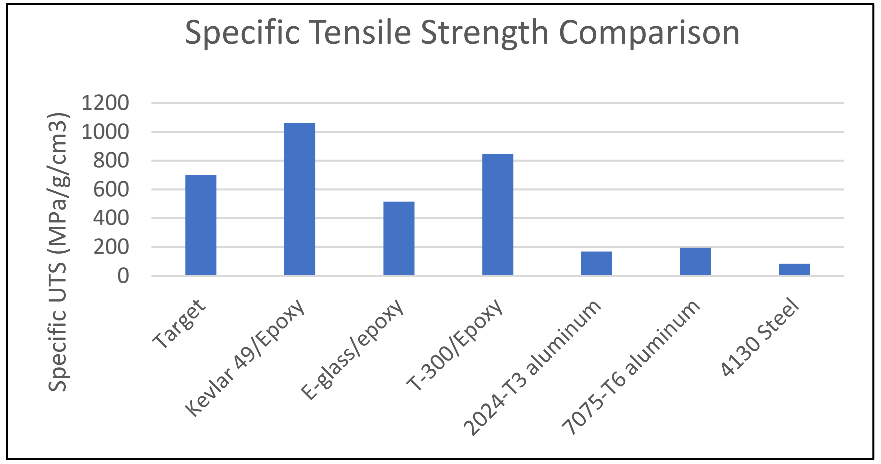
Objective

Develop a low-cost high-performance thermoplastic polymer-matrix/polymer-fiber composite system with the following goals:

- Specific mechanical properties comparable to traditional composite systems
- 30% lighter than traditional composite systems
- $15/kg material cost
- 3-minute cycle time



"Compression moulding" by CORE-Materials is licensed with CC BY-NC-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-sa/2.0/



Impact

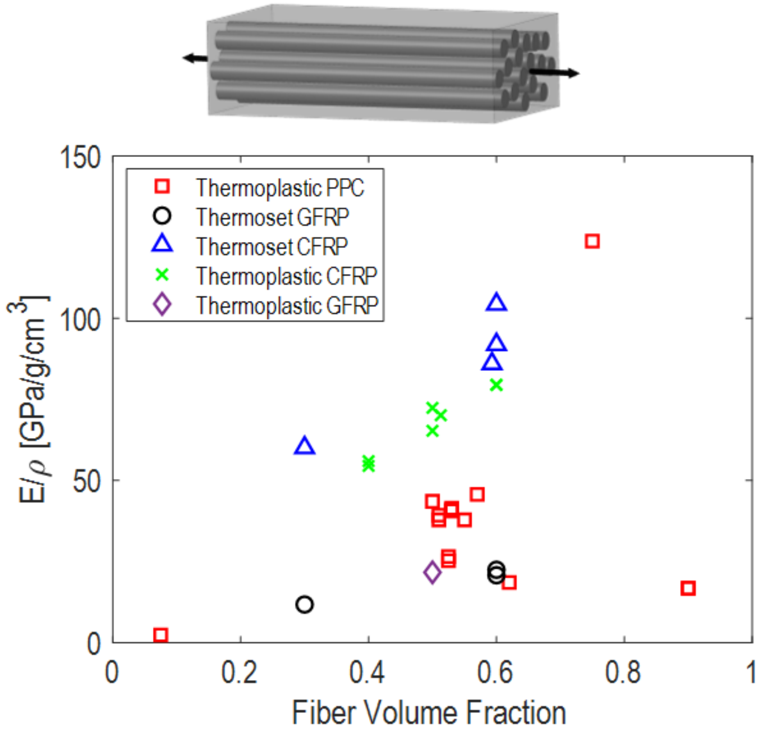
- Lightweight materials can reduce vehicle weight ~50%
  - 40% fuel efficiency increase
  - **Offsets weight from batteries & electric motors**
- Minimum of 50% cost reduction in materials
- Fully thermoplastic composite system increases recyclability

To date, development of such a material has been limited by the strength of thermoplastic fibers and the thermal stability of these fibers during processing with the matrix

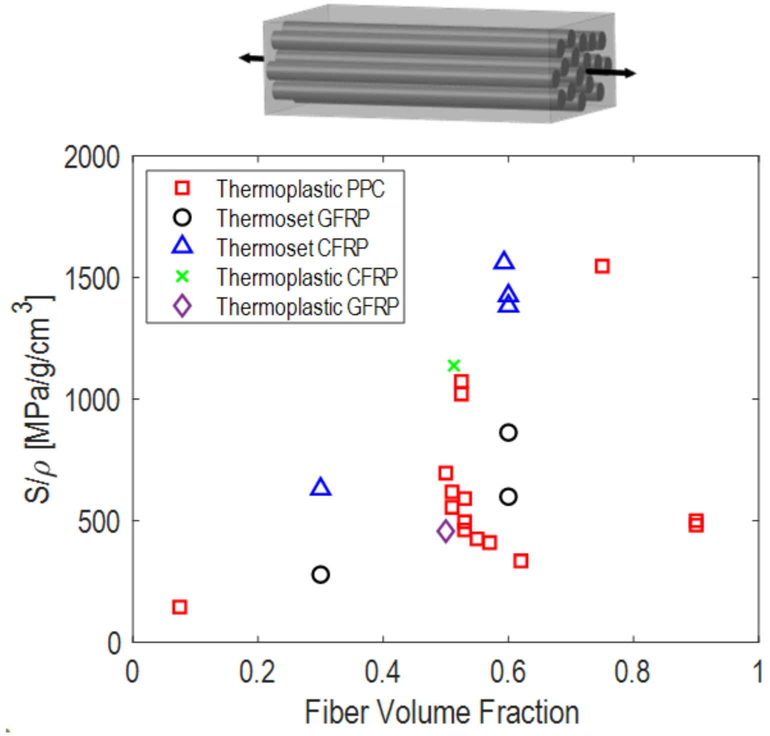
Relevance

Uni-axial tension on uni-directional polymer/polymer composites (longitudinal direction)

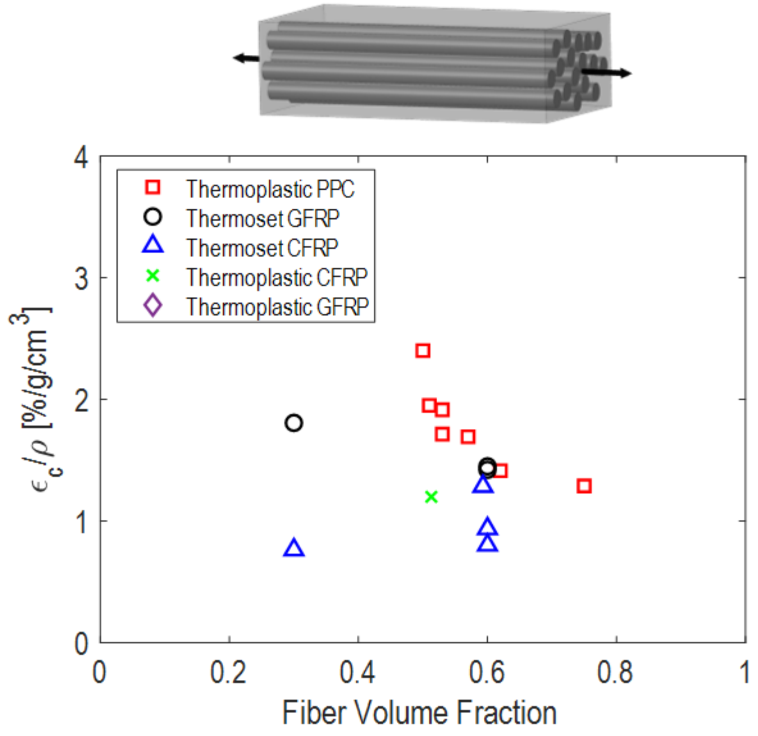
Elastic Modulus



Tensile Strength

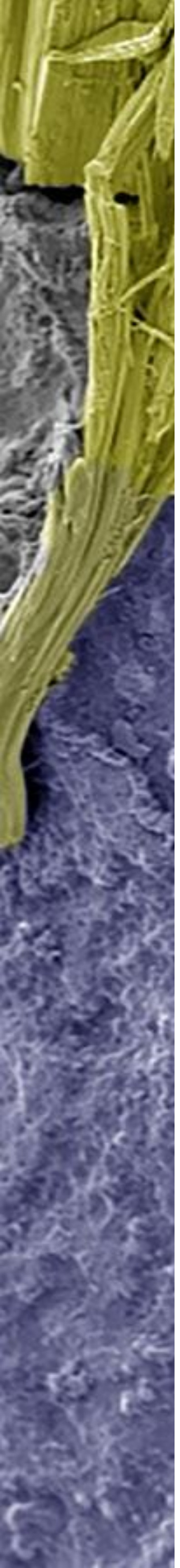


Failure Strain



PPC = Semi-Crystalline Polymer/Polymer Composite (Vectran, Polypropylene, High Density Polyethylene fibers)
GFRP = Glass Fiber Reinforced Polymer
CFRP = Carbon Fiber Reinforced Polymer

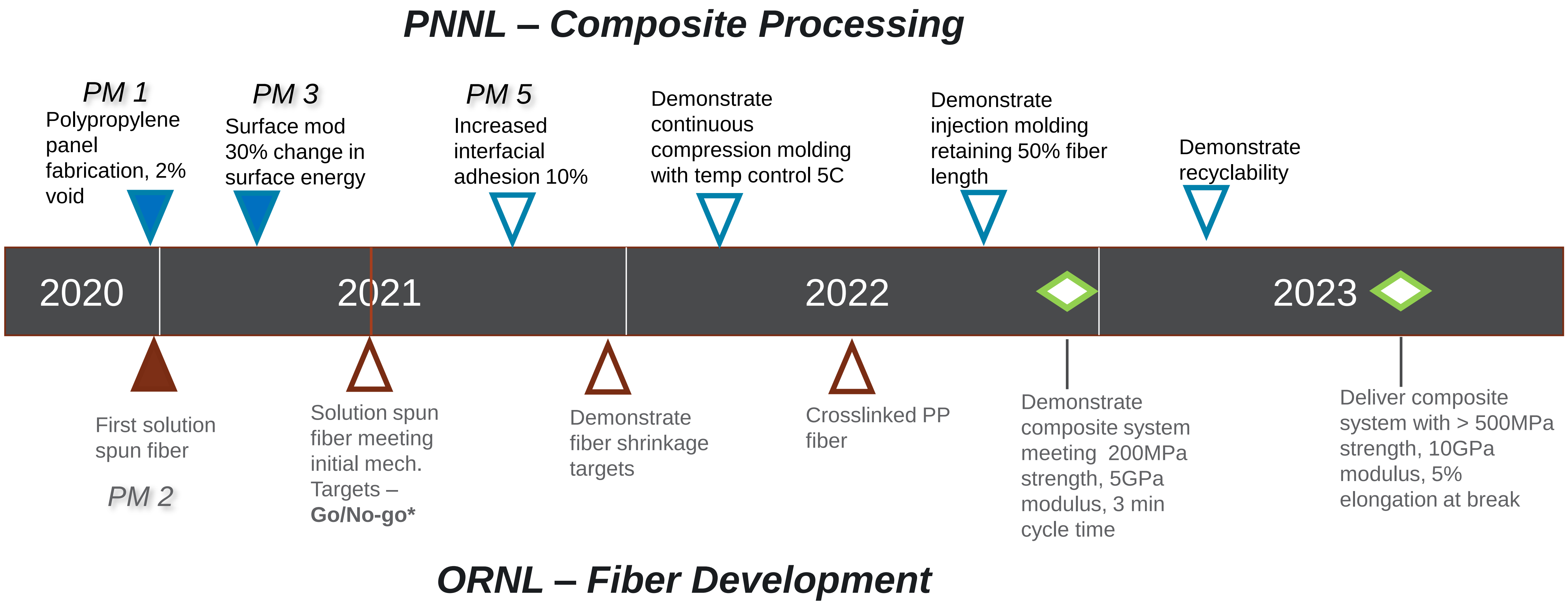
To date, development of a thermoplastic/thermoplastic material has been limited by the strength of the fibers and the thermal stability of these fibers during processing with the matrix



Pacific Northwest NATIONAL LABORATORY

Milestones

OAK RIDGE National Laboratory



Approach

Fiber Development - ORNL

Melt spun fiber
Solution spun fiber
Heat drawing

Optimized Material System

Process Development - PNNL

Key process parameters & tolerances
Ideal matrix materials
Fiber surface modification process
Recycling process

Fiber Characterization
- Strength
- Thermal Stability
- Morphology

Matrix & Composite Characterization
- Thermal analysis
- Mechanical properties
- Interfacial adhesion
- Laminate morphology

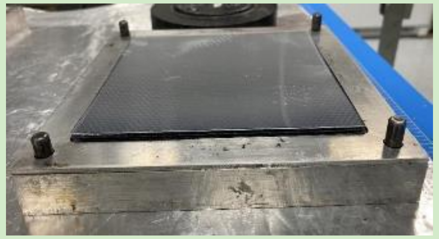
What is the material system and process parameters needed to meet the technical goals?
What modifications can be made to the individual components to achieve this?

Technical Accomplishments and Progress

Project Milestone 1

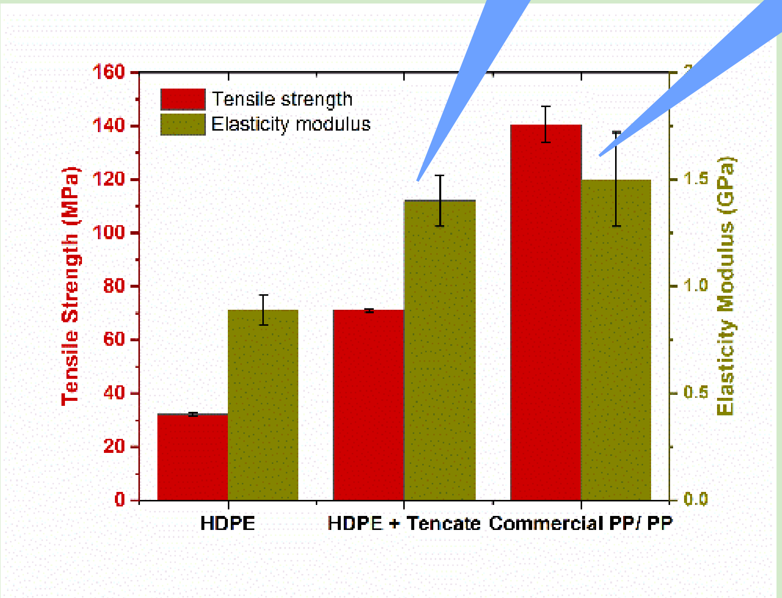
Polypropylene (PP) panel fabrication

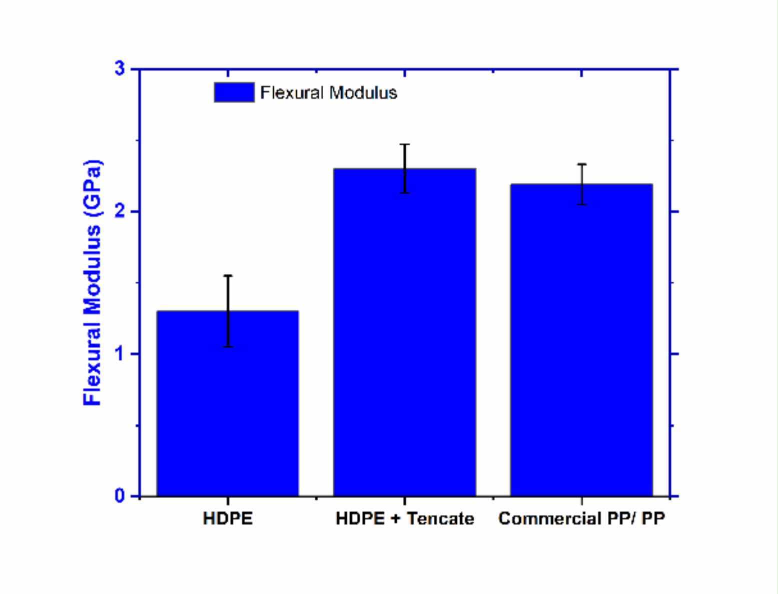
- Standardized film stacking process developed
  - Fiber shrinkage prevented
  - Percent crystallinity of matrix maintained
  - Less than 2% void fraction achieved
  - Demonstrated with multiple thermoplastic matrix materials
    - ✓ PP matrix/PP fiber
    - ✓ HDPE matrix/PP fiber
    - ✓ LDPE matrix/PP fiber



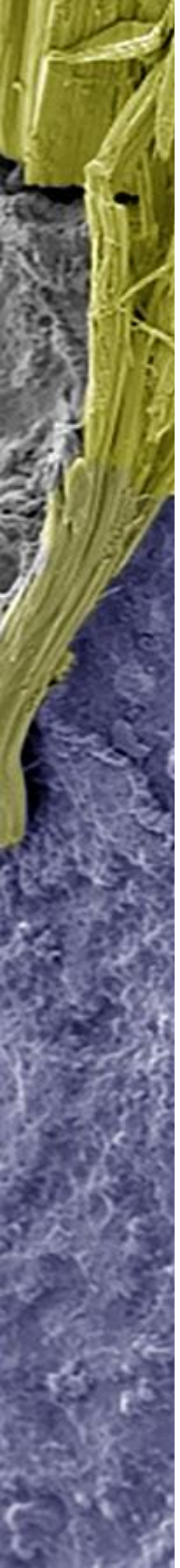
33 wt % fiber

For reference only – 80 wt% fiber content





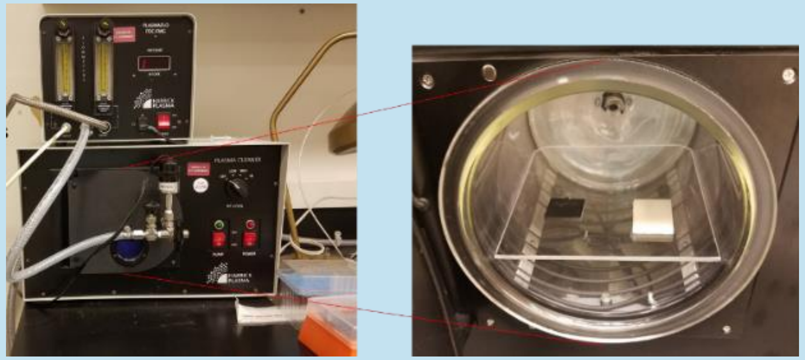
Panel fabrication goals met through process control and material choice
Fiber surface modification will be critical to achieving mechanical property targets



Technical Accomplishments and Progress

Project Milestone 3

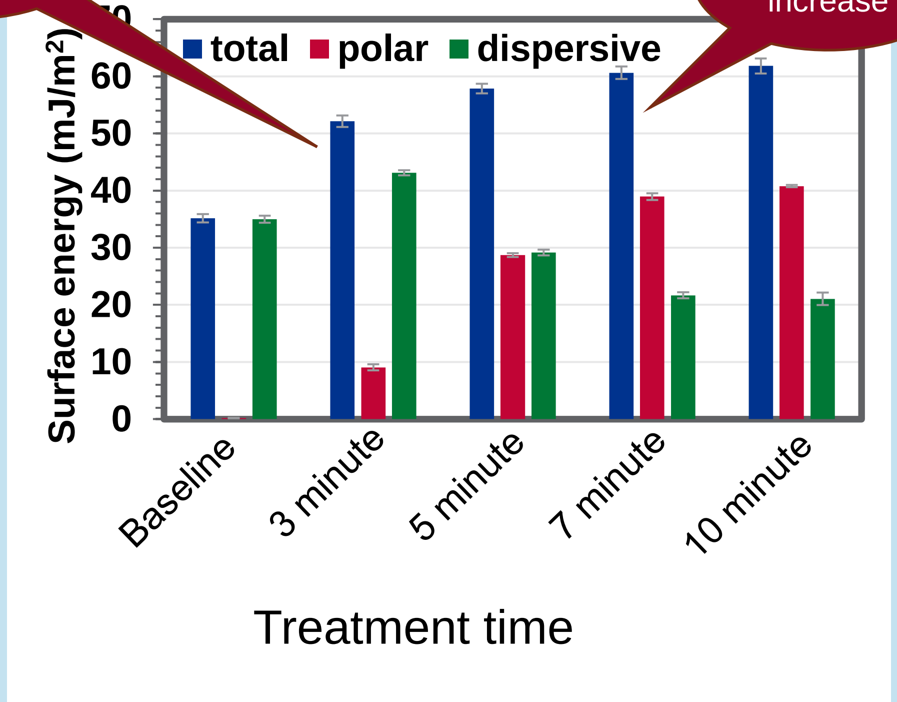
- Fiber surface modification process resulting in > 30% surface energy improvement
- Enhanced functionality for improved adhesion with matrix resin systems



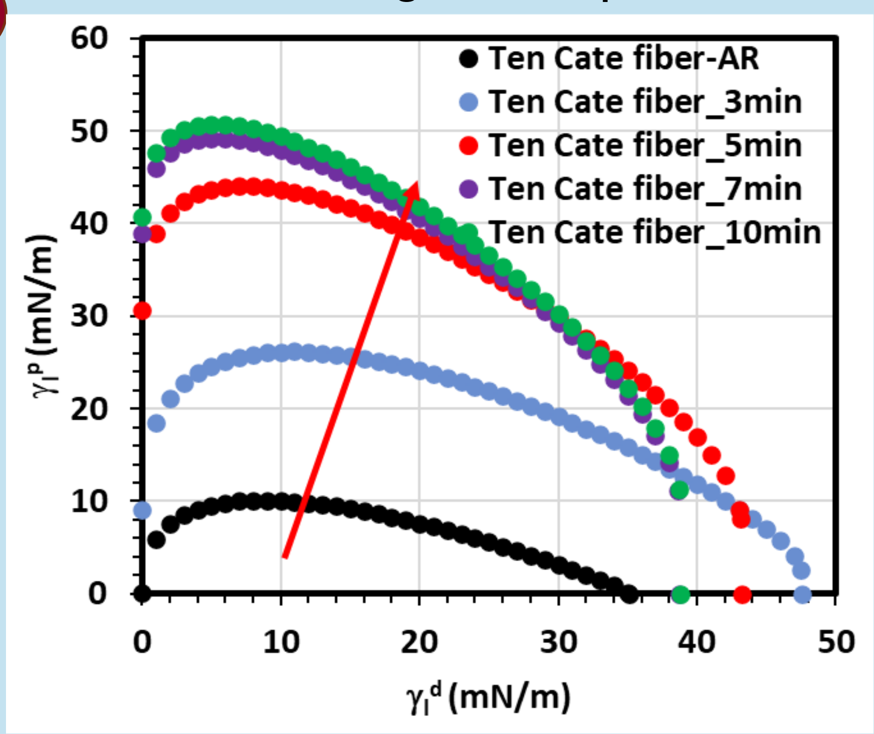
Low power oxygen plasma
Polypropylene fiber

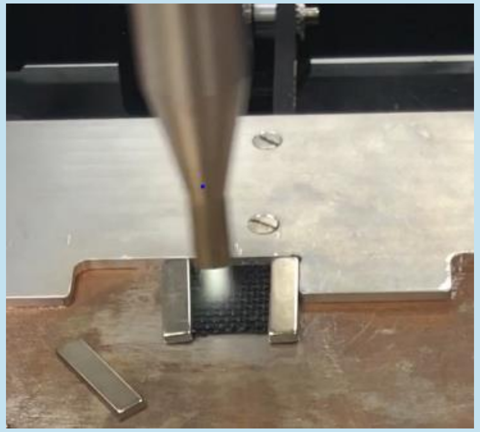
Nearly 50% increase

Nearly 2x increase



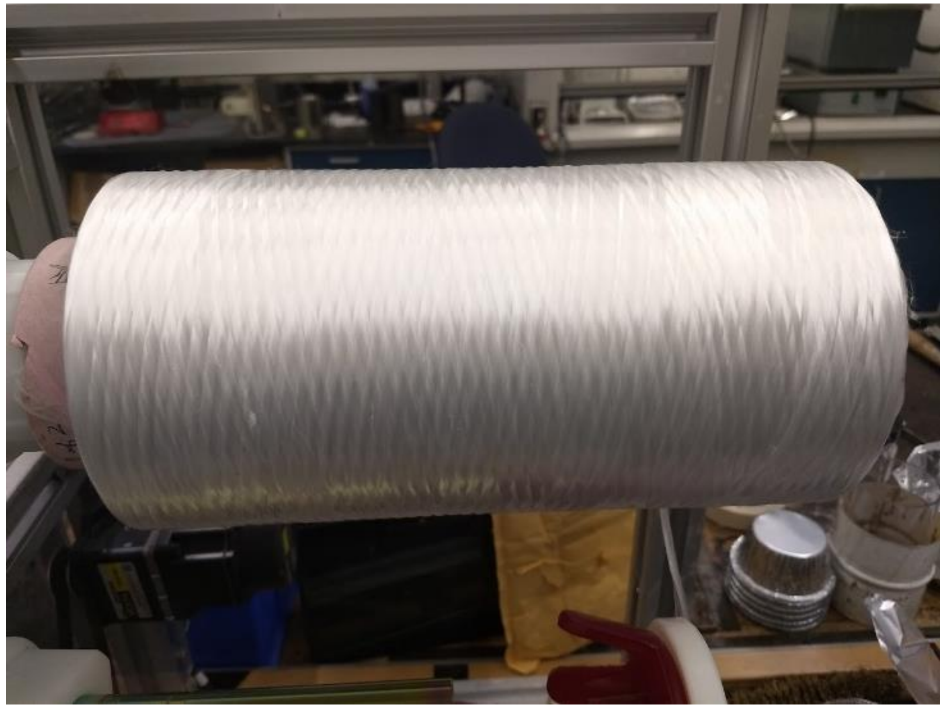
Wetting Envelope



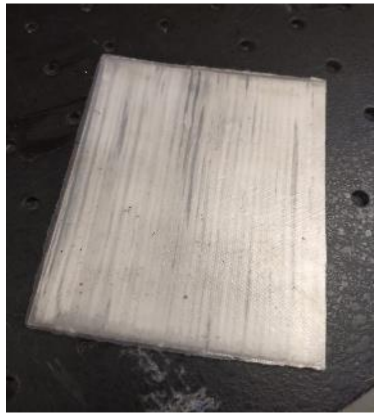


Fiber surface modification goal exceeded with low power oxygen plasma treatment

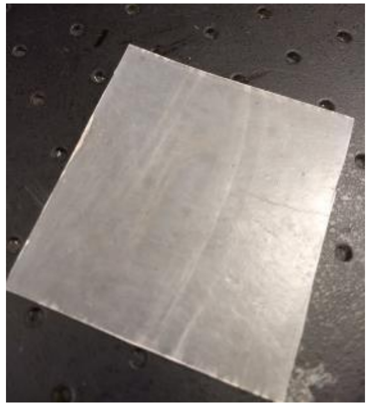
Technical Accomplishments and Progress



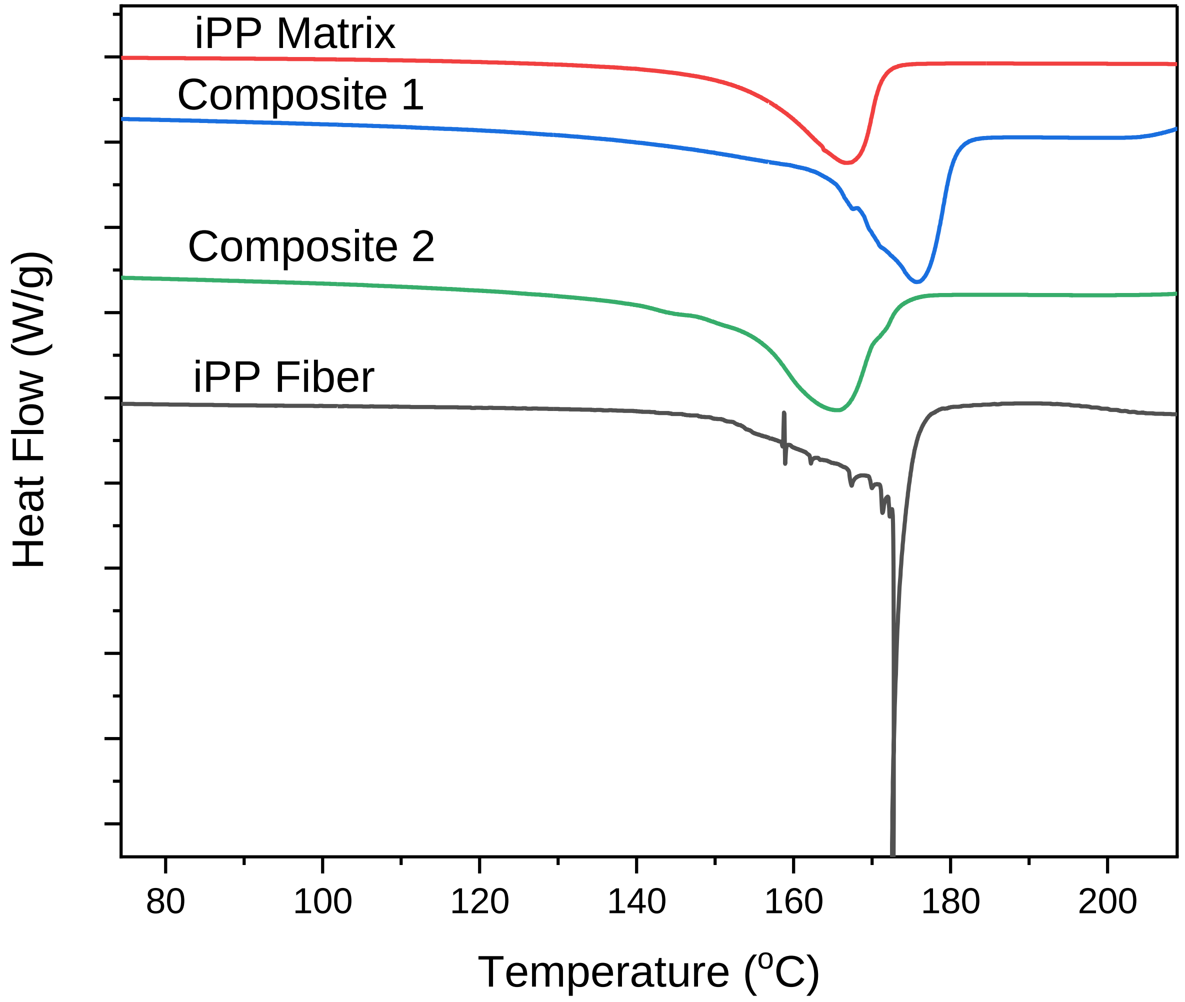
Currently using melt-spun PP with ~400 MPa tensile strength at ~50% crystallinity. Can we make fibers with >700 MPa tensile strength and >15 GPa modulus by increasing the crystallinity above 70%?



iPP Composite 1
Temperature 165°C



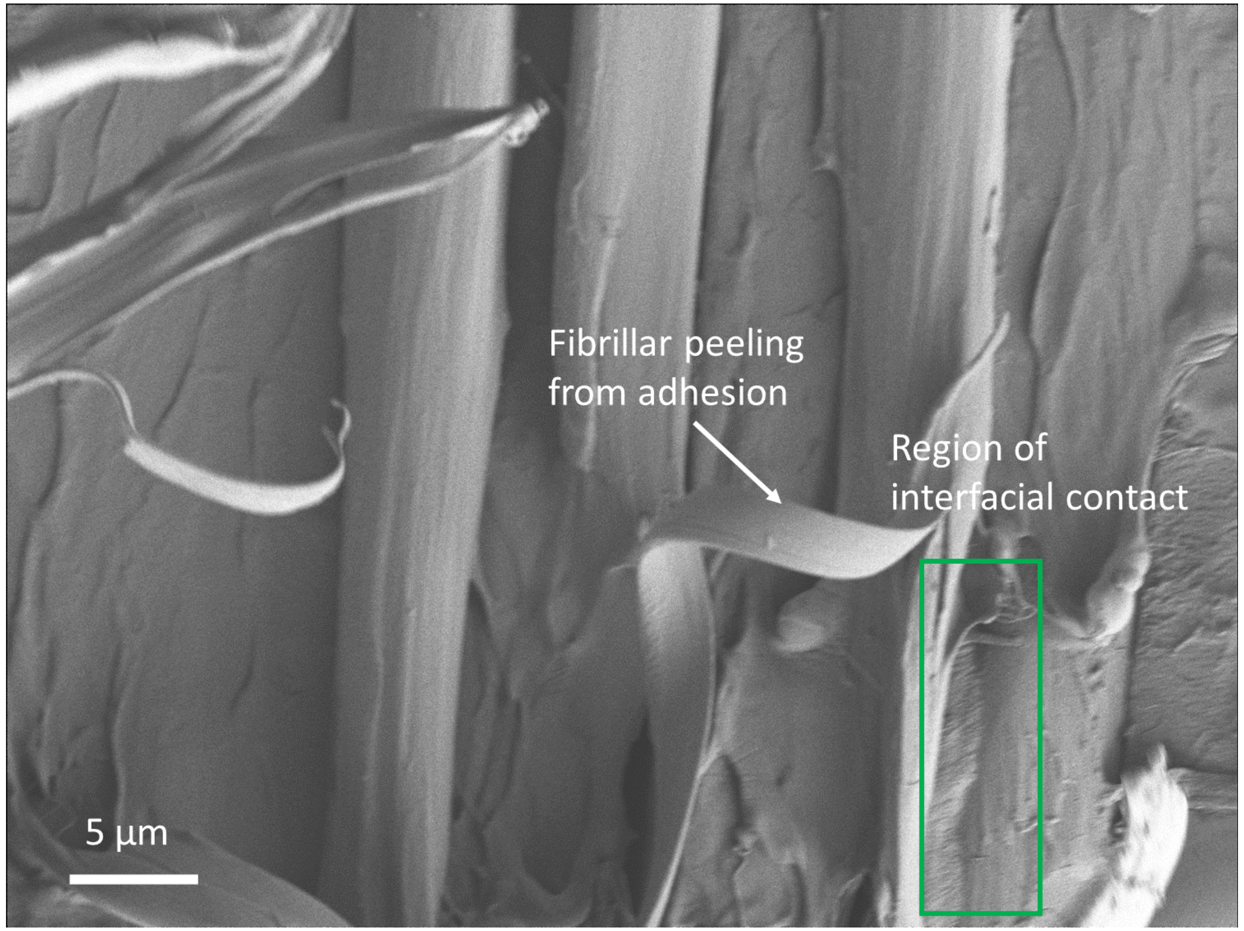
iPP Composite 2
Temperature 176°C



Effectively utilized narrow processing window to fabricate composite with no fiber fusion and with fiber fusion.

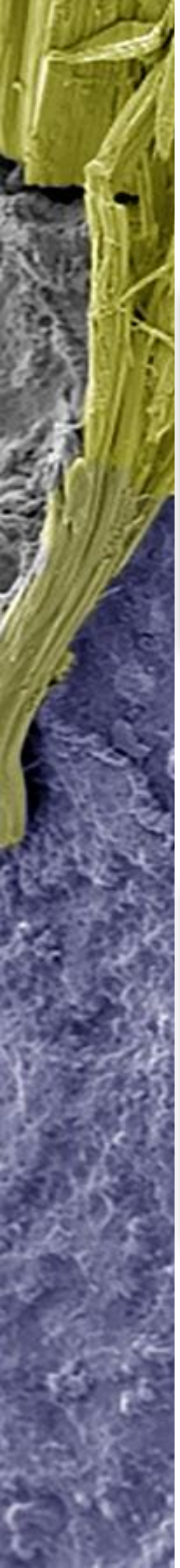
Technical Accomplishments and Progress

Scanning electron microscope (SEM) of iPP Composite 2 showing integration of fiber into matrix



SEM of fracture interface shows superior adhesion between fiber and matrix

ORNL is developing new iPP fiber spinning method for ultra high strength and stiffness at lower density.



Collaboration and Coordination

PNNL

Characterization for commercially available fibers

Matrix interaction with commercially available fibers

Key panel processing parameters

Fiber surface modification process

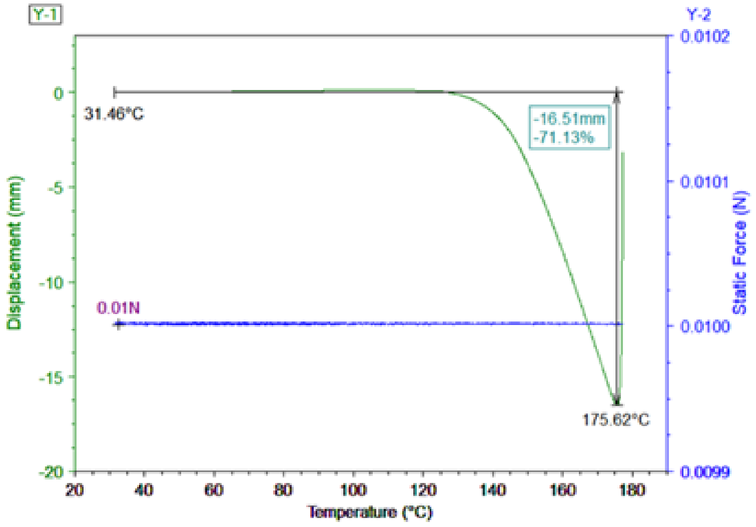
<u>Fiber development</u>

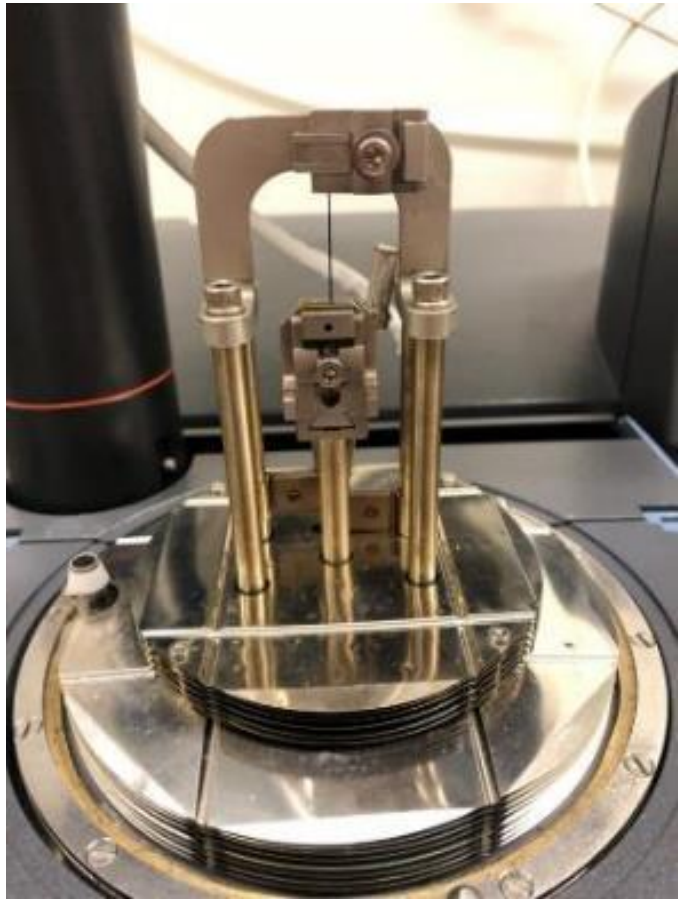
- Minimal shrinkage
- Optimized strength
- Provide to PNNL for further composite study

<u>Characterization</u>

- Thermal analysis
- Mechanical evaluation
- Morphology observation
- Comparison with commercial fibers evaluated from PNNL

ORNL





Responses to Previous Year Reviewers' Comments

This is a new start project and was not previously reviewed

Proposed Future Research

PNNL

Project Milestone 3 & 5 (9/30/2021)

- Develop air plasma treatment process that provides for 30% surface energy improvement
  - Evaluate on fiber developed by ORNL
- Test interfacial adhesion of plasma treated fibers

Project Milestone 7 (3/31/2022)

- Evaluate additional fabrication processes
  - Filament winding – unidirectional fibers
  - Injection molding – chopped fibers, woven fibers
  - Continuous compression molding
  - Fiber tow impregnation process development – injection molding & weaving of impregnated fiber tows
- Identify matrix material for fiber developed by ORNL
- Develop molding process for parts with increasing complexity

ORNL

Project Milestones

- Develop 1st thermoplastic fiber (PP) spinning system for very high molecular weight polymers; spin and draw 10 meters of polymer fiber for testing.
  - Along with performing traditional fiber spinning methods (melt and solution), a new spinning method is being developed (gel).
  - Spinneret heads are being designed to control fiber morphologies.
- Demonstrate a fiber with 500 MPa fiber strength and >10 GPa Young's modulus with a >10% strain to failure.
  - We are developing heat setting conditions for fiber to avoid shrinkage force at molding condition (minimal temperature 150 C).
  - Nanoparticle loading is optional. Will be used if needed to enhance the modulus and dimensional stability.

Any proposed future work is subject to change based on funding levels

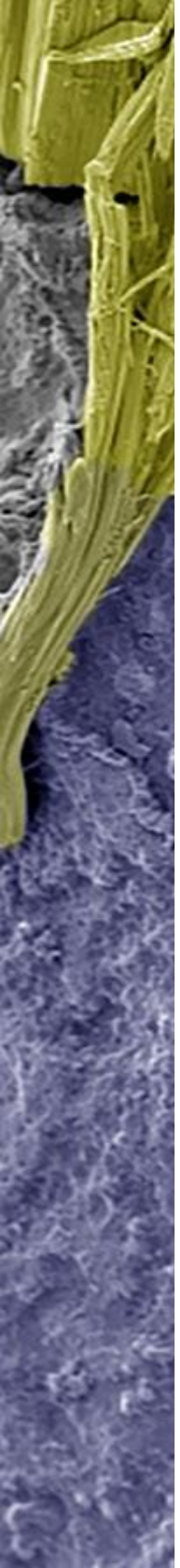
Summary

Impact to VTO Objectives

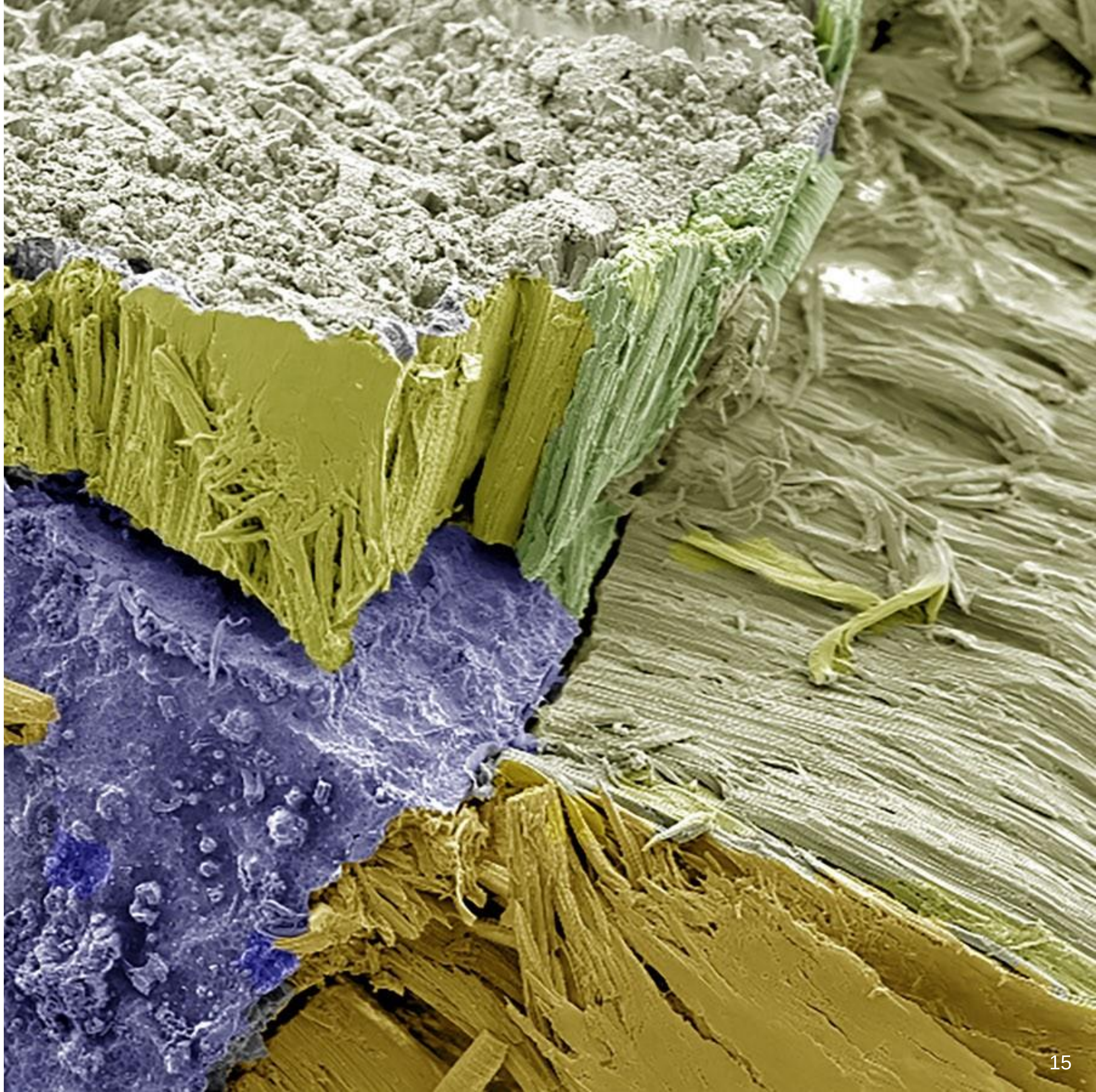
This project utilizes a high strength thermoplastic fiber developed by ORNL integrated into a thermoplastic matrix to produce a composite material with comparable specific mechanical properties, reduced weight, and reduced cost when compared to typical carbon fiber composites.

Accomplishments

- Fabricated thermoplastic polymer/polymer panels with <2% void content
- Demonstrated surface modification process that exceeds goal of increasing surface energy 30%



Thank you



Technical Backup Slides

Divider slide

Technical Backup Slides

References for Slide 4:

1. Daniel IM, Ishai, O. Engineering Mechanics of Composite Materials. Oxford University Press, 2006.
2. Pegoretti A, Zanolli A, Migliaresi C. Preparation and tensile mechanical properties of unidirectional liquid crystalline single-polymer composites. Compos Sci and Technol 2006;66(13):1970-79.
3. Alcock B, Cabrera NO, Barkoula NM, Loos J, Pejis, T. The Mechanical Properties of Unidirectional Properties of Unidirectional All-polypropylene Composites. Compos Part A 2006;37(5):716-26.
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5. Teishev A, Marom G. The effect of transcrystallinity on the transverse mechanical properties of single-polymer polyethylene composites. Applied Polymer 1995;56:959-66.
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7. Botelho E, Figiel L, Rezende MC, Lauke B. Mechanical behavior of carbon fiber reinforced polyamide composites. Compos Sci and Technol 2003;63(13):1843-55.